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Govyadinov et al.

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(54) **FLUID EJECTION ASSEMBLY WITH CIRCULATION PUMP**

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B41J 2/175 (2006.01)
B41J 2/14 (2006.01)

(52) **U.S. Cl.**
CPC ***B41J 2/17596*** (2013.01); *B41J 2002/14467* (2013.01); ***B41J 2/1404*** (2013.01); ***B41J 2/1753*** (2013.01); ***B41J 2/14145*** (2013.01); *B41J 2002/14387* (2013.01)
USPC **347/85**; 347/67

(58) **Field of Classification Search**
CPC B41J 2/14056
USPC 347/85, 67
See application file for complete search history.

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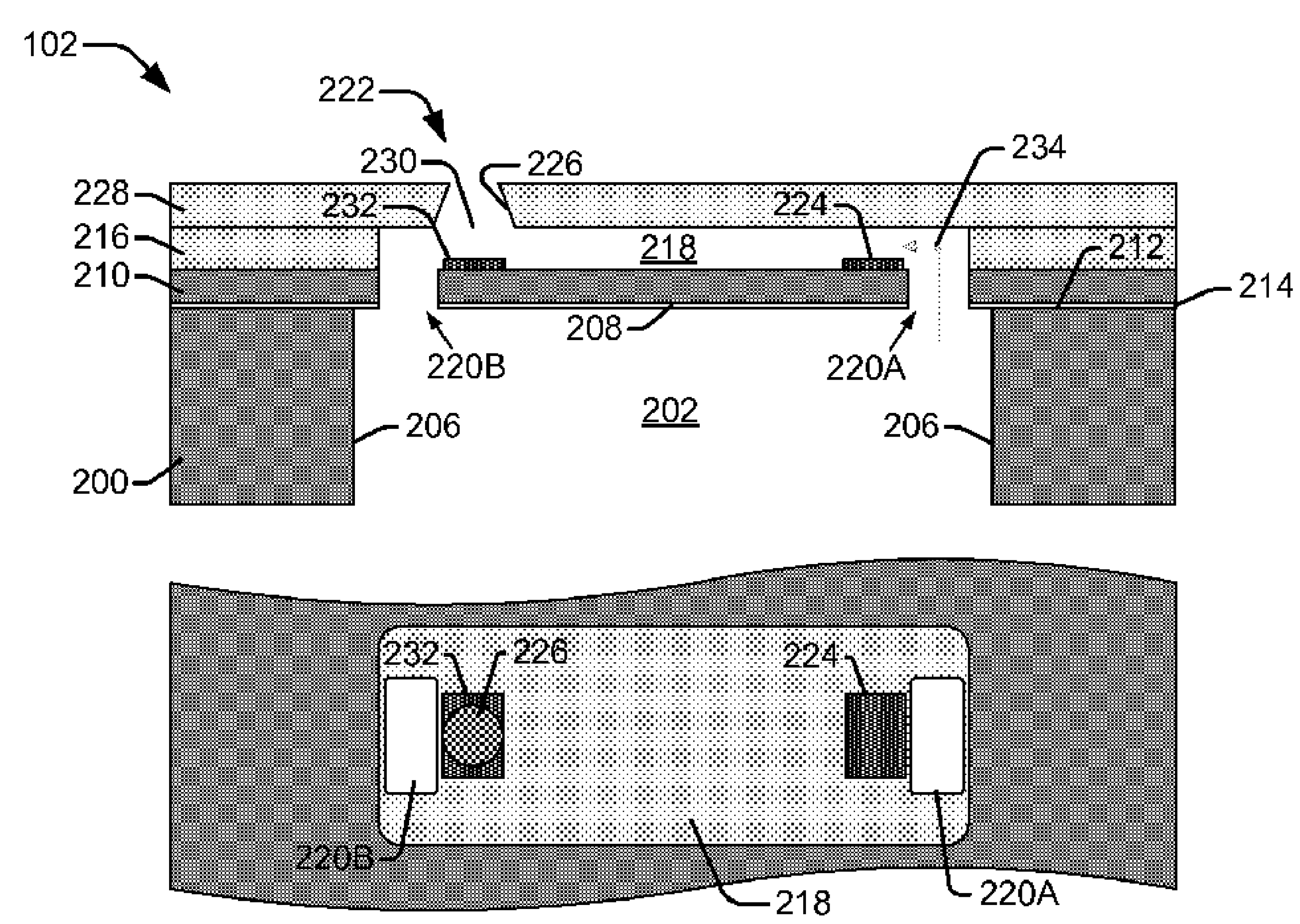
(57) **ABSTRACT**

A fluid ejection assembly includes a fluid slot formed in a first substrate and a channel formed in a chamber layer disposed on top of a second substrate. The bottom surface of the second substrate is adhered to the top surface of the first substrate and fluid feed holes are formed between the fluid slot and the channel. A fluid ejection element is at a first end of the channel and a pump element is at a second end of the channel to circulate fluid horizontally through the channel and vertically through the fluid feed holes.

12 Claims, 9 Drawing Sheets



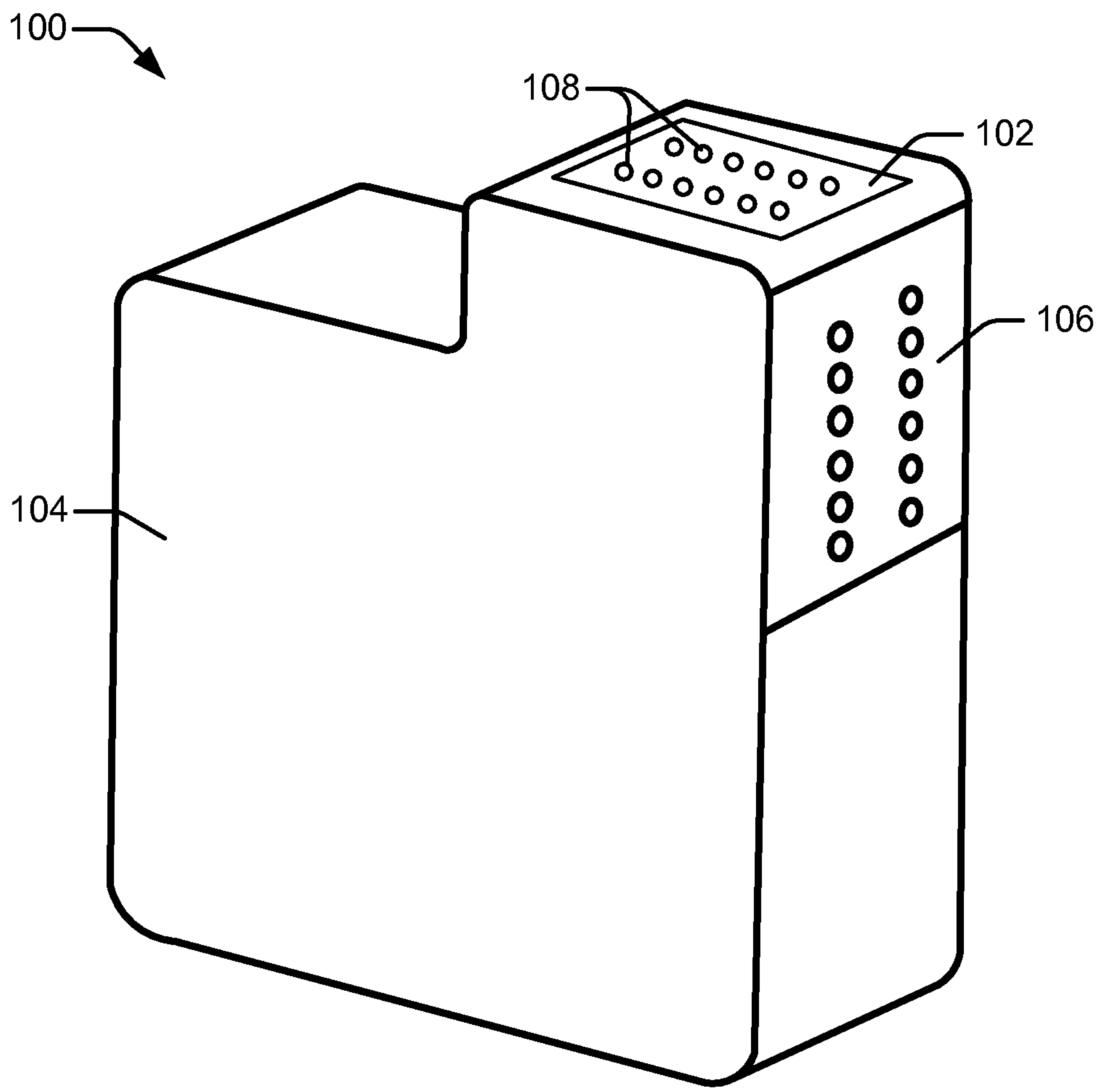


FIG. 1

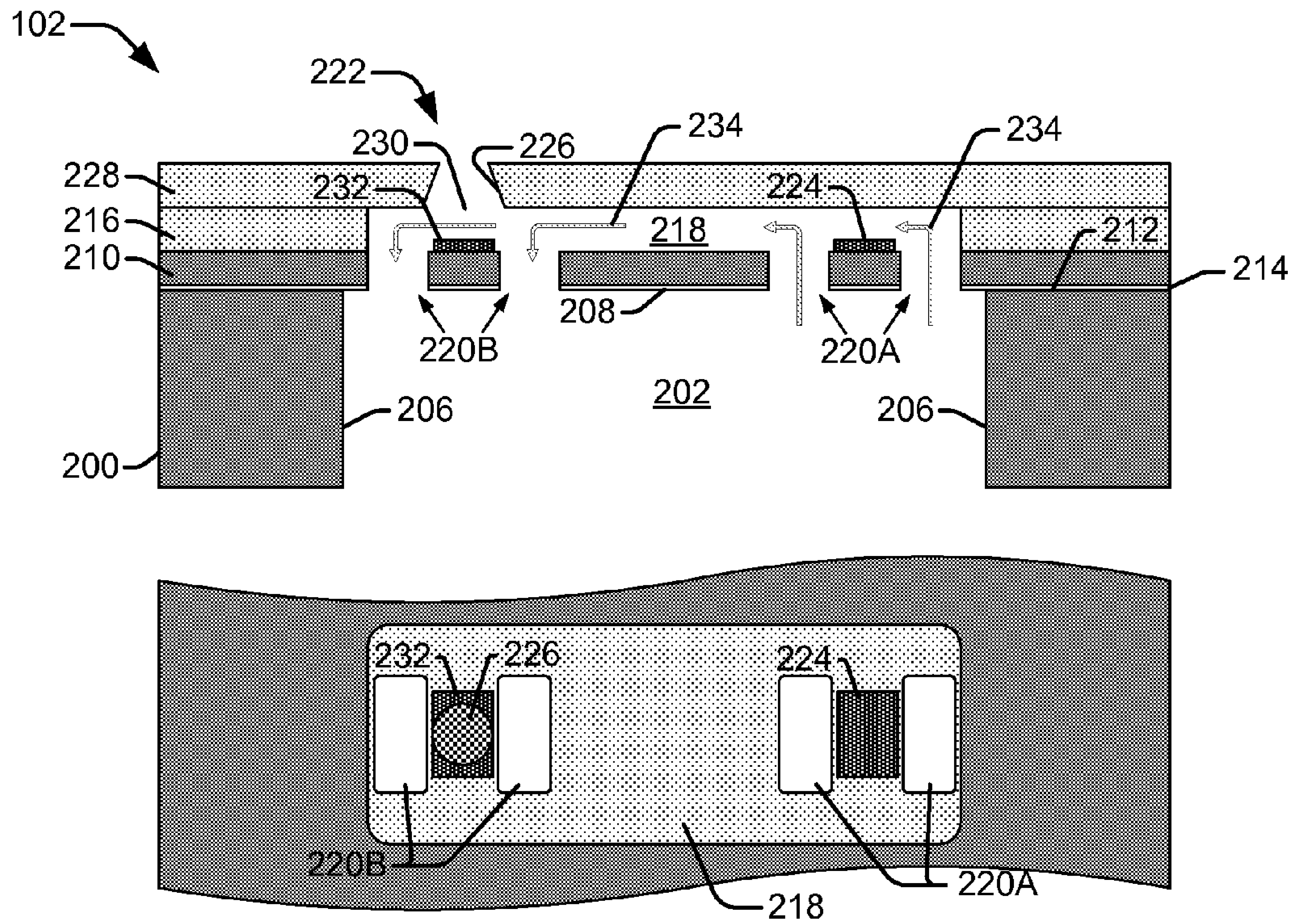

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FIG. 2A

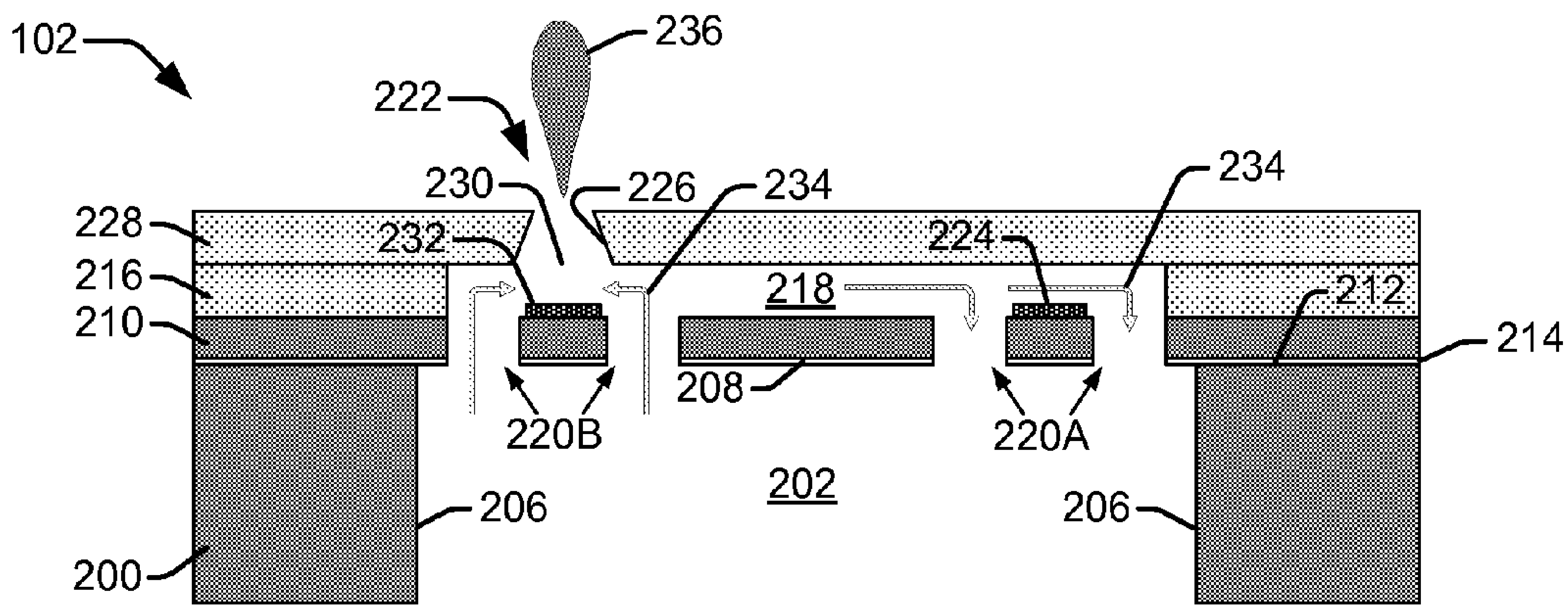
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FIG. 2B

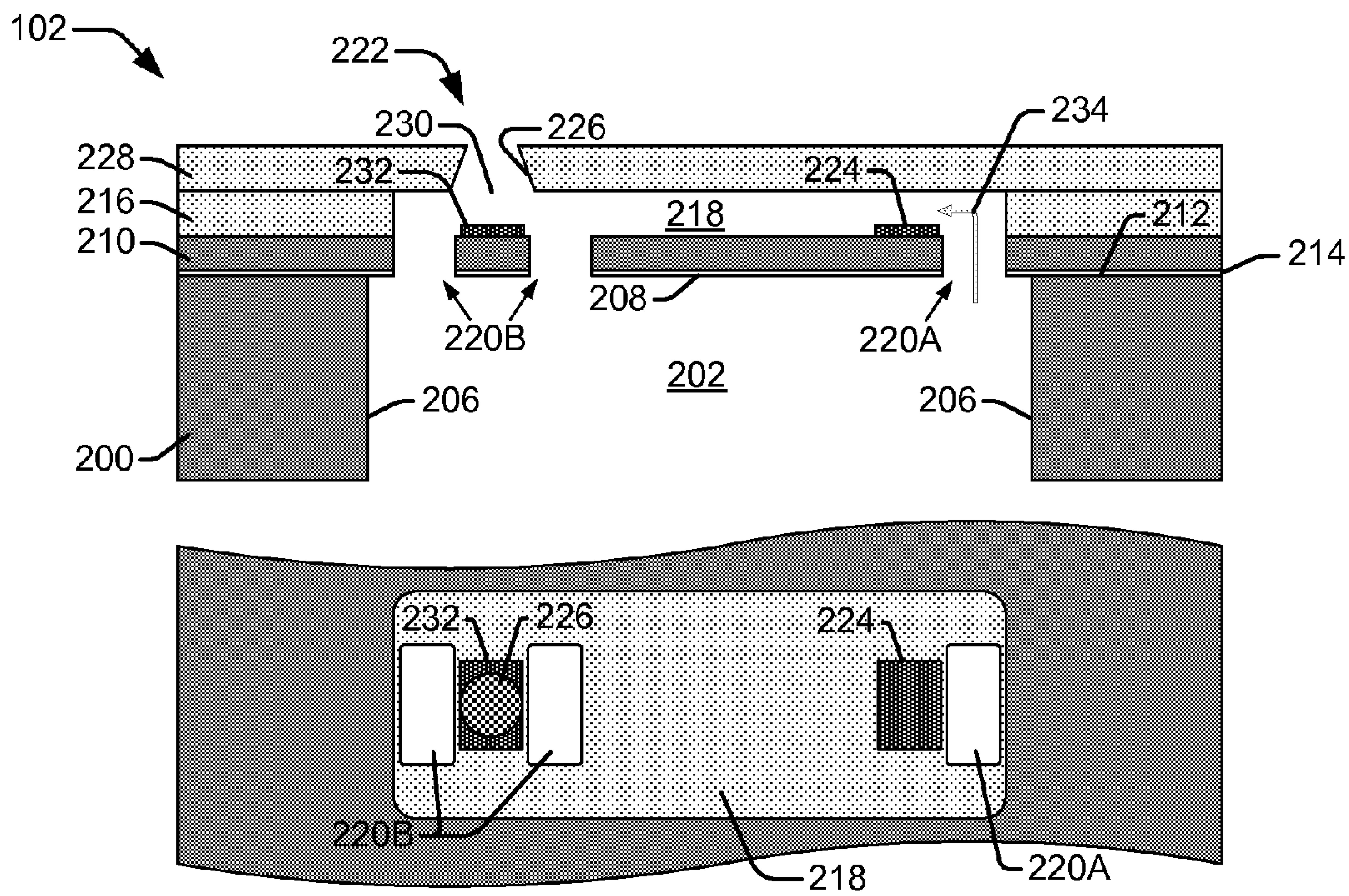
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FIG. 3

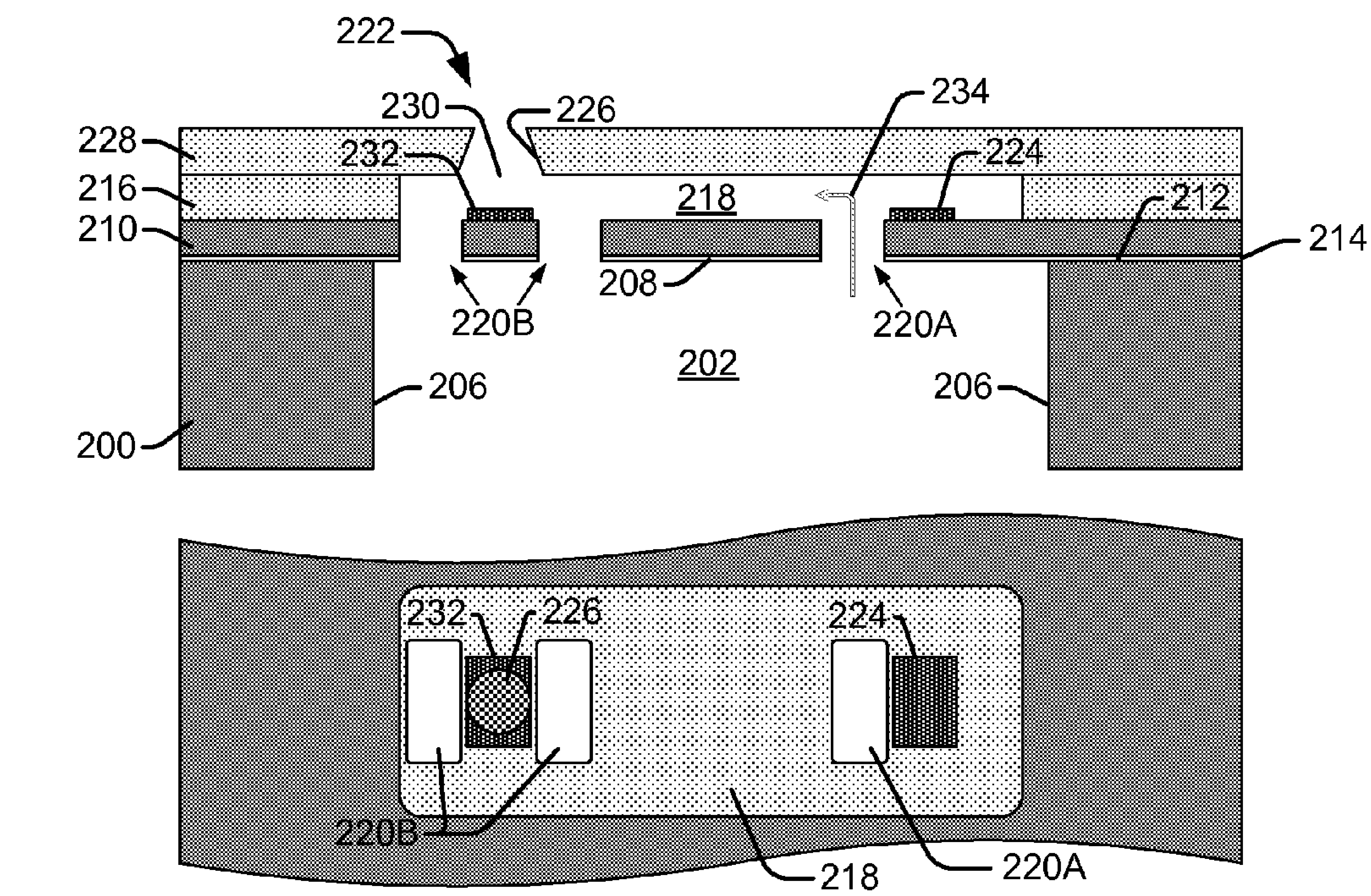
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FIG. 4

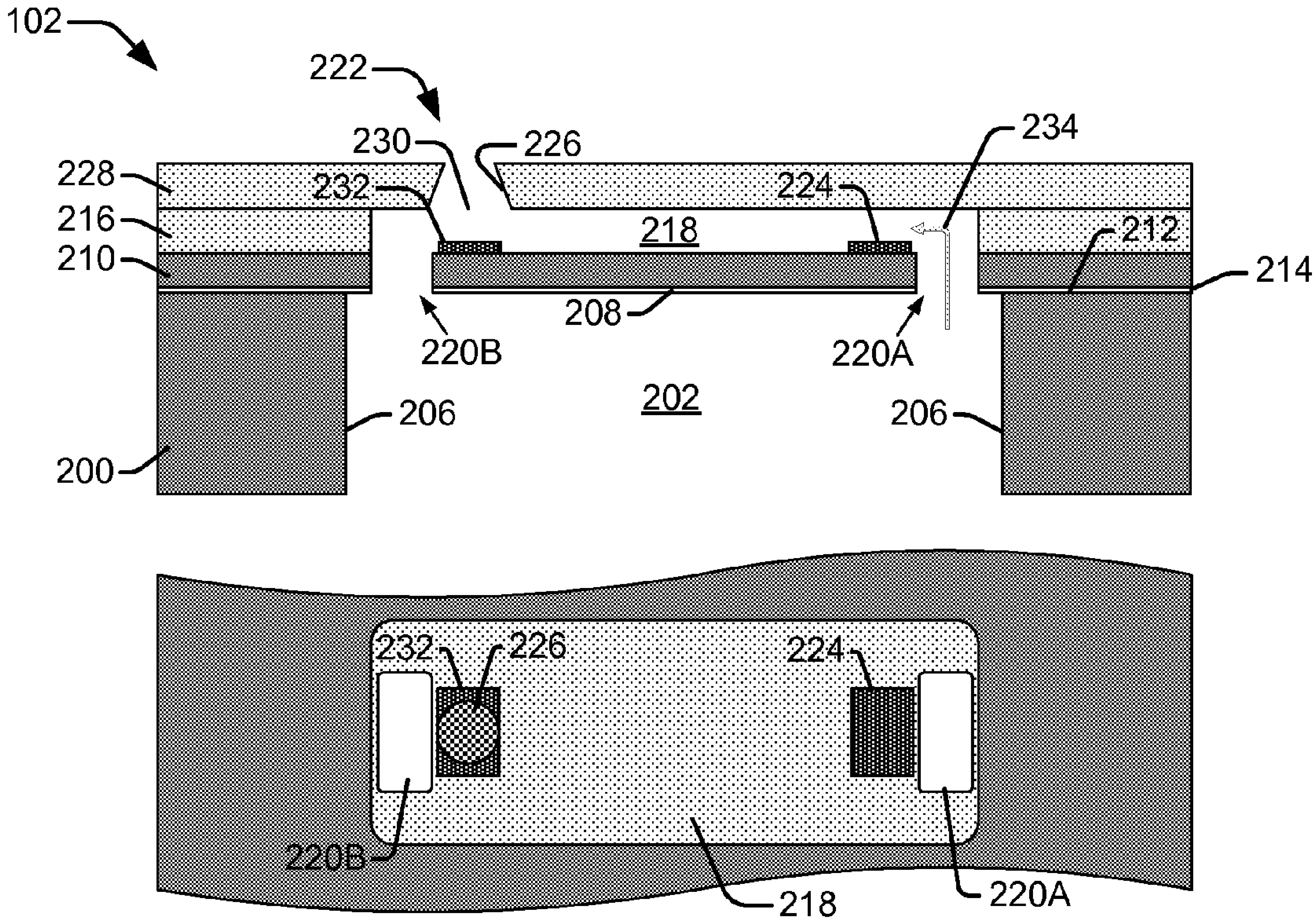
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FIG. 5

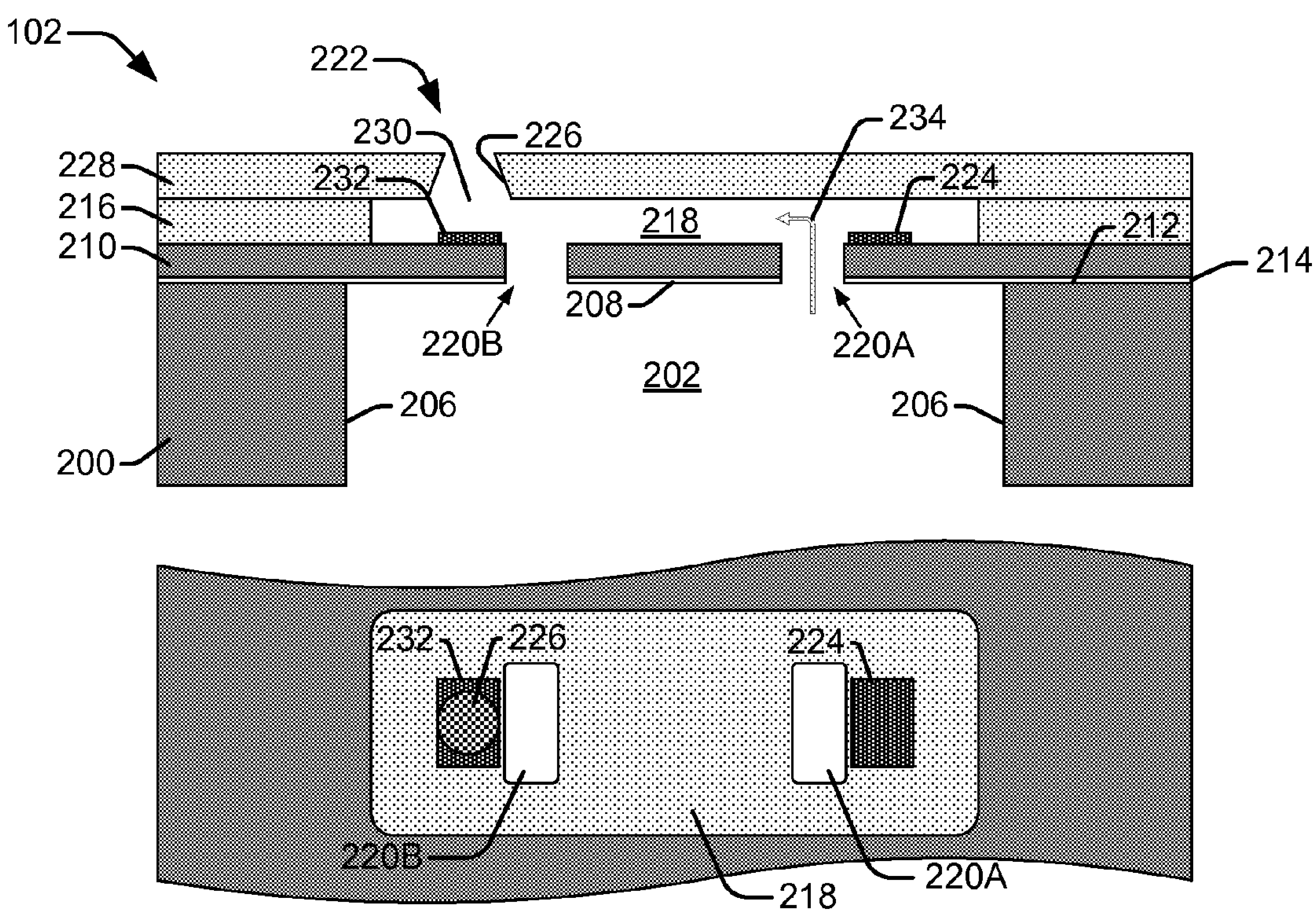
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FIG. 6

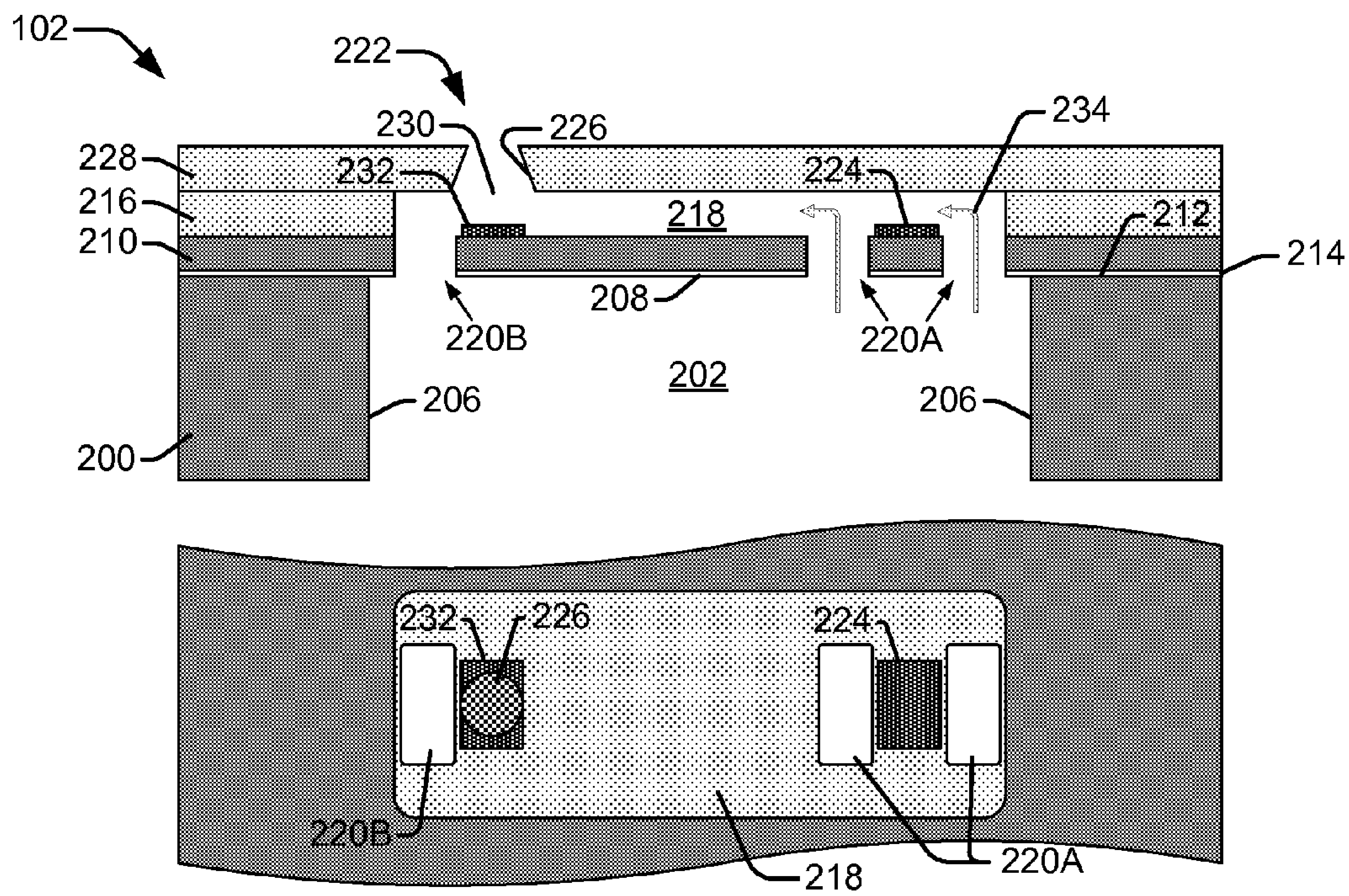
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FIG. 7

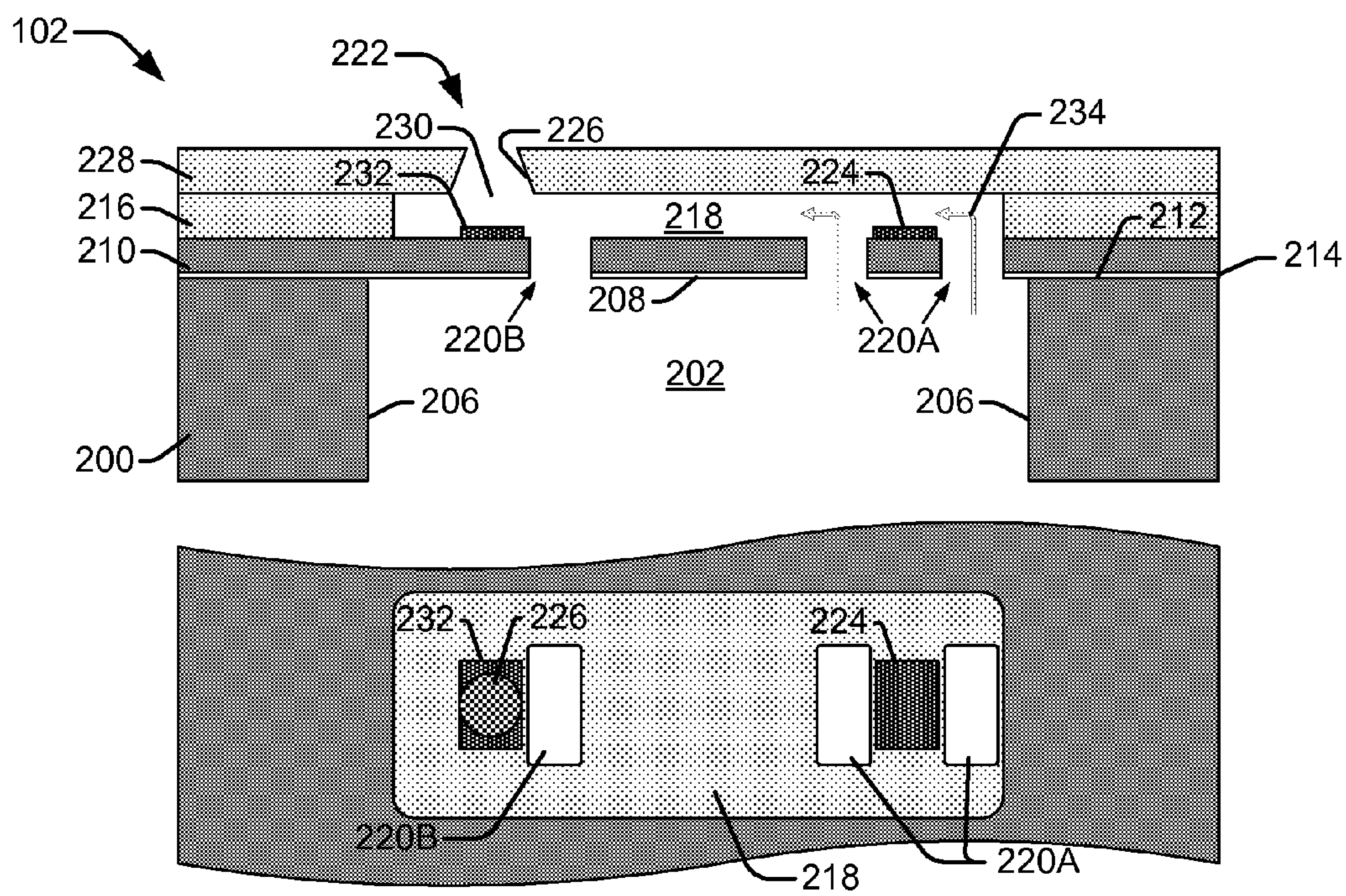
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FIG. 8

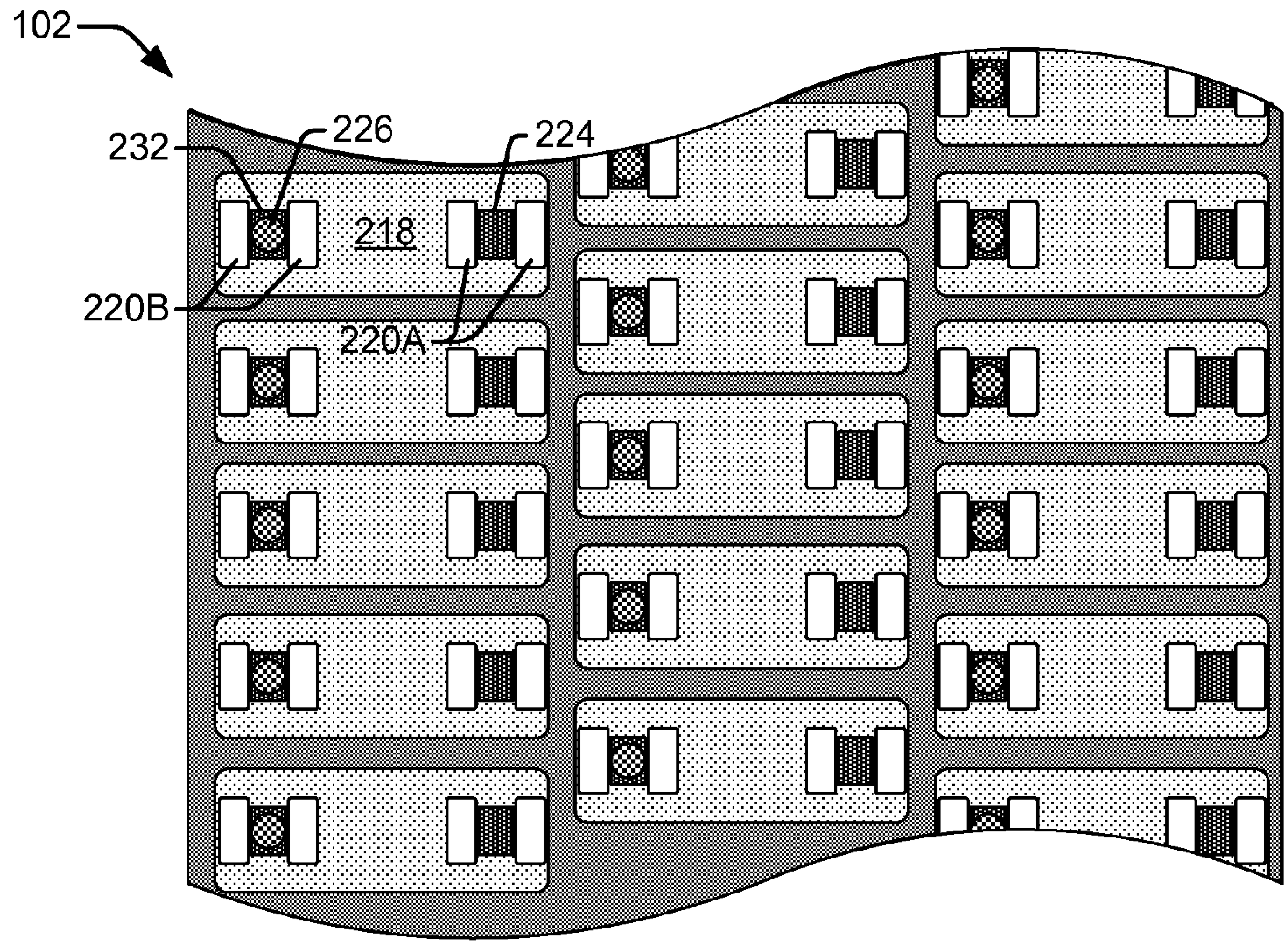

FIG. 9

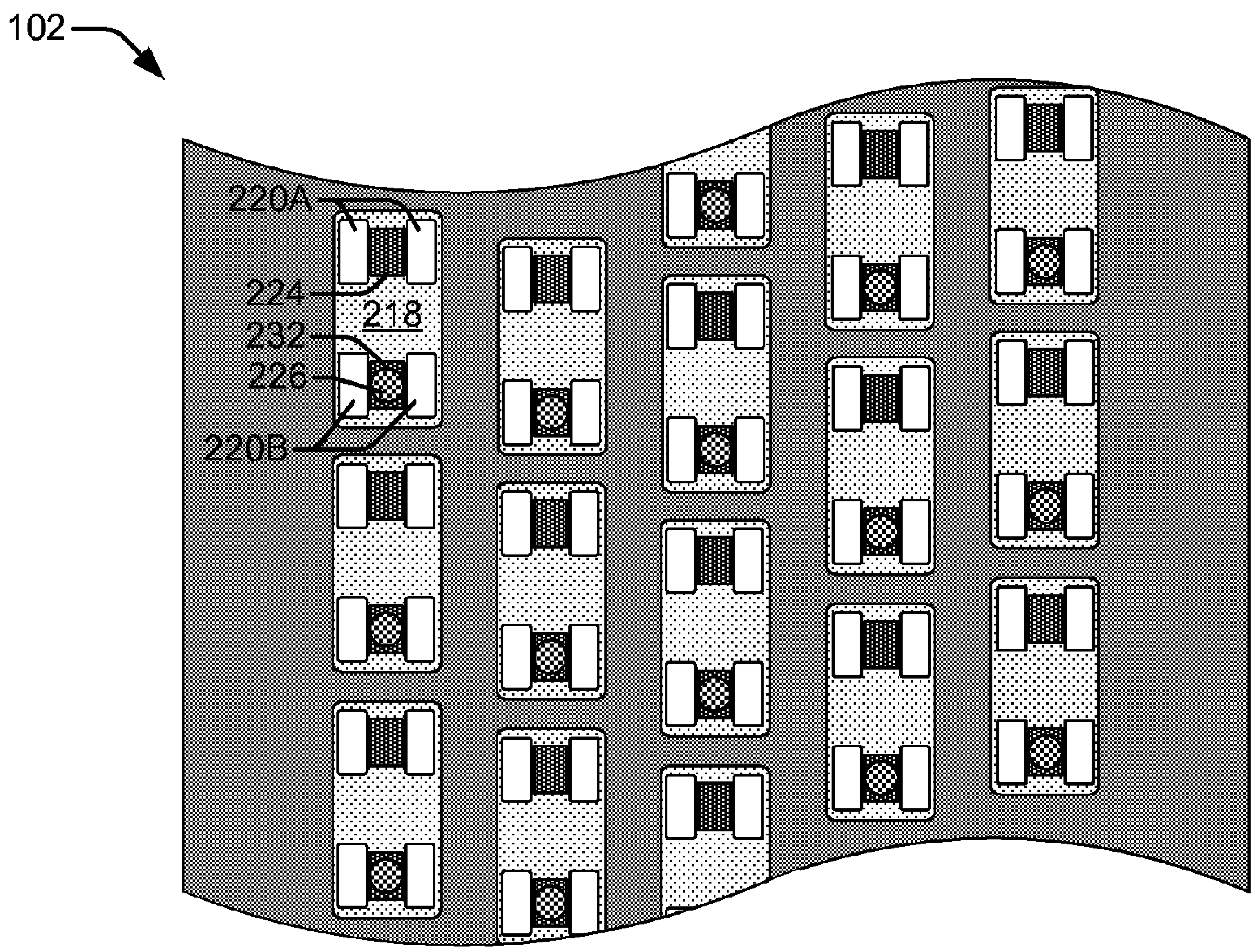

FIG. 10

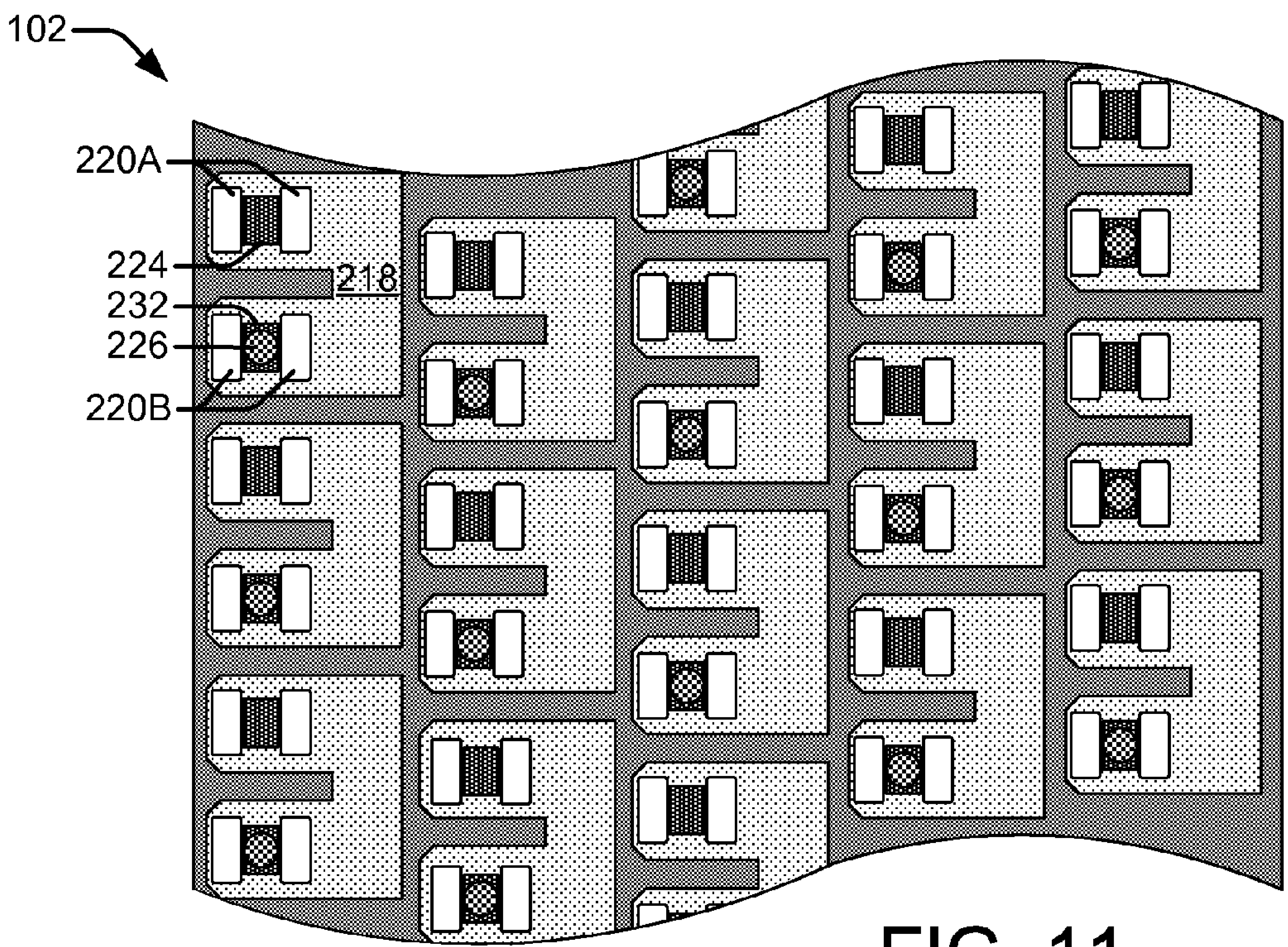

FIG. 11

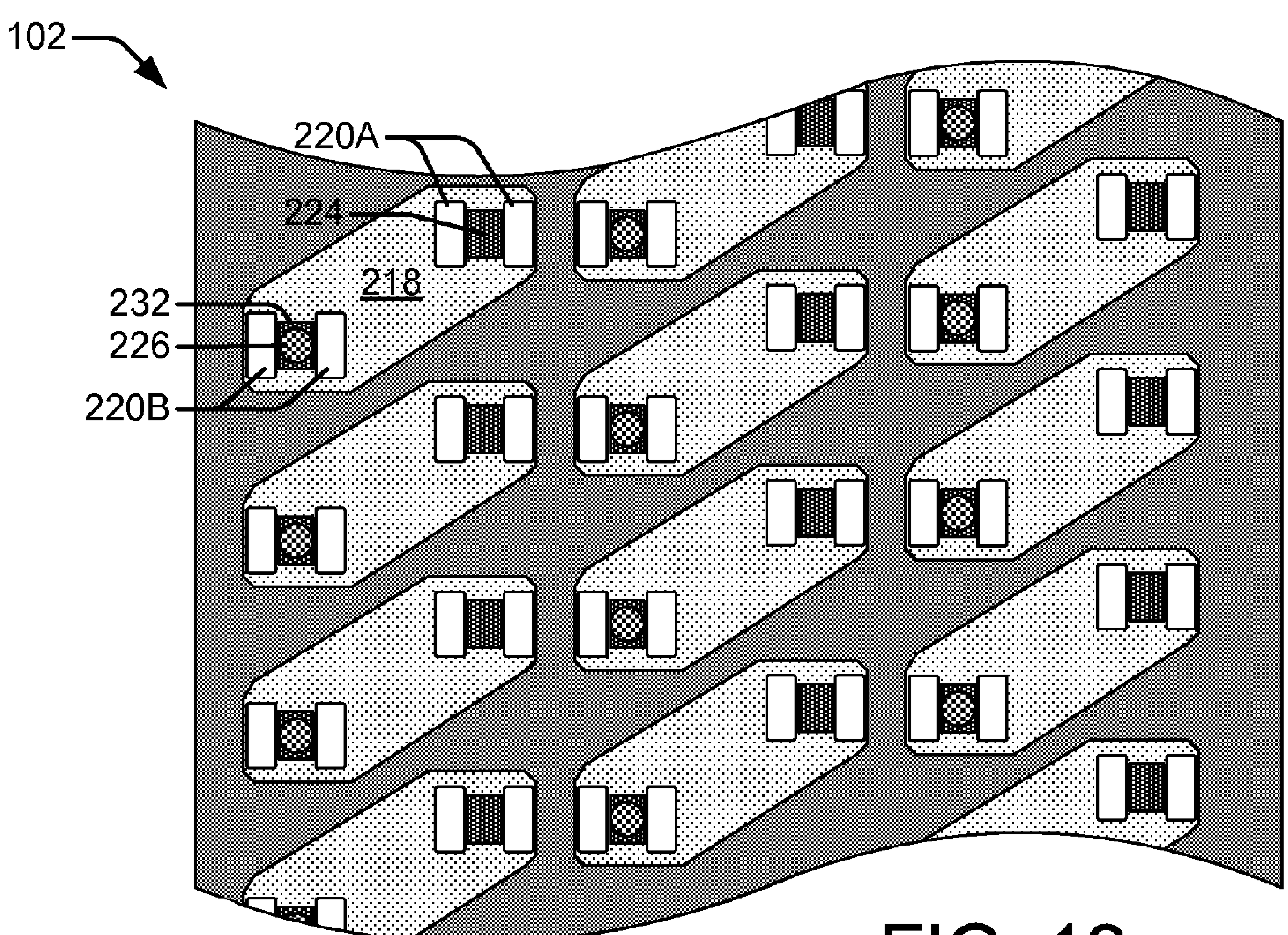

FIG. 12

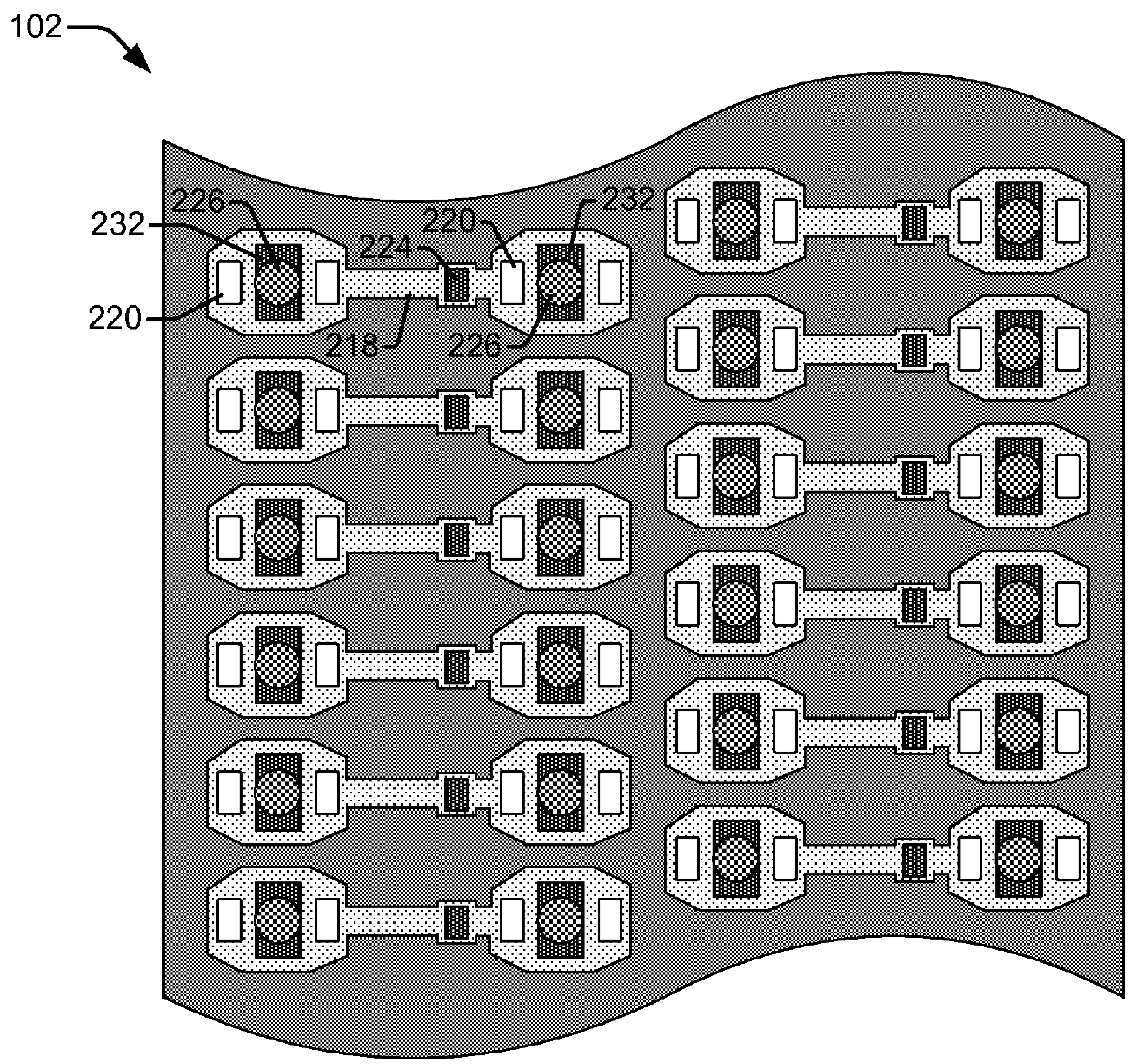

FIG. 13

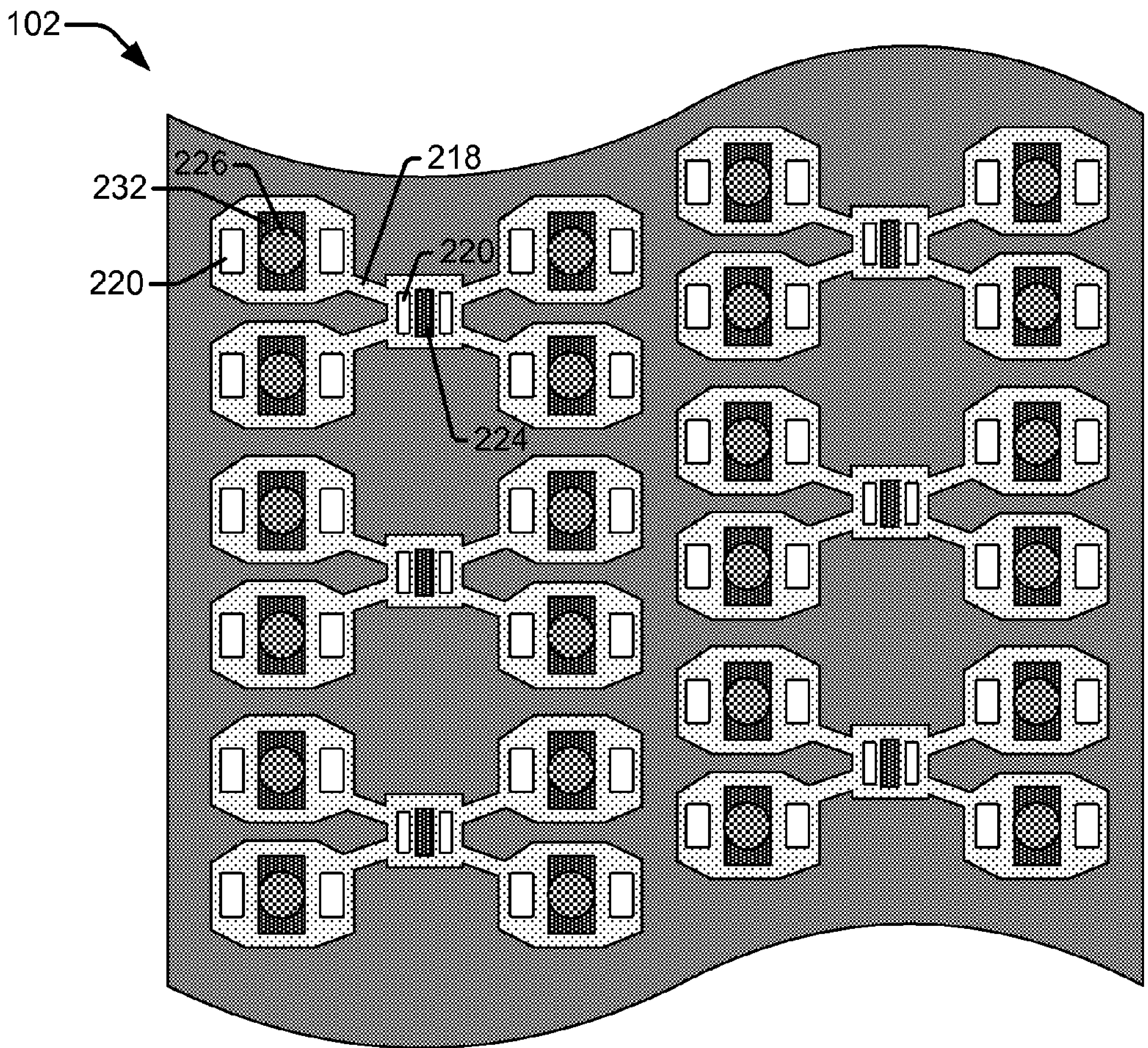
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FIG. 14

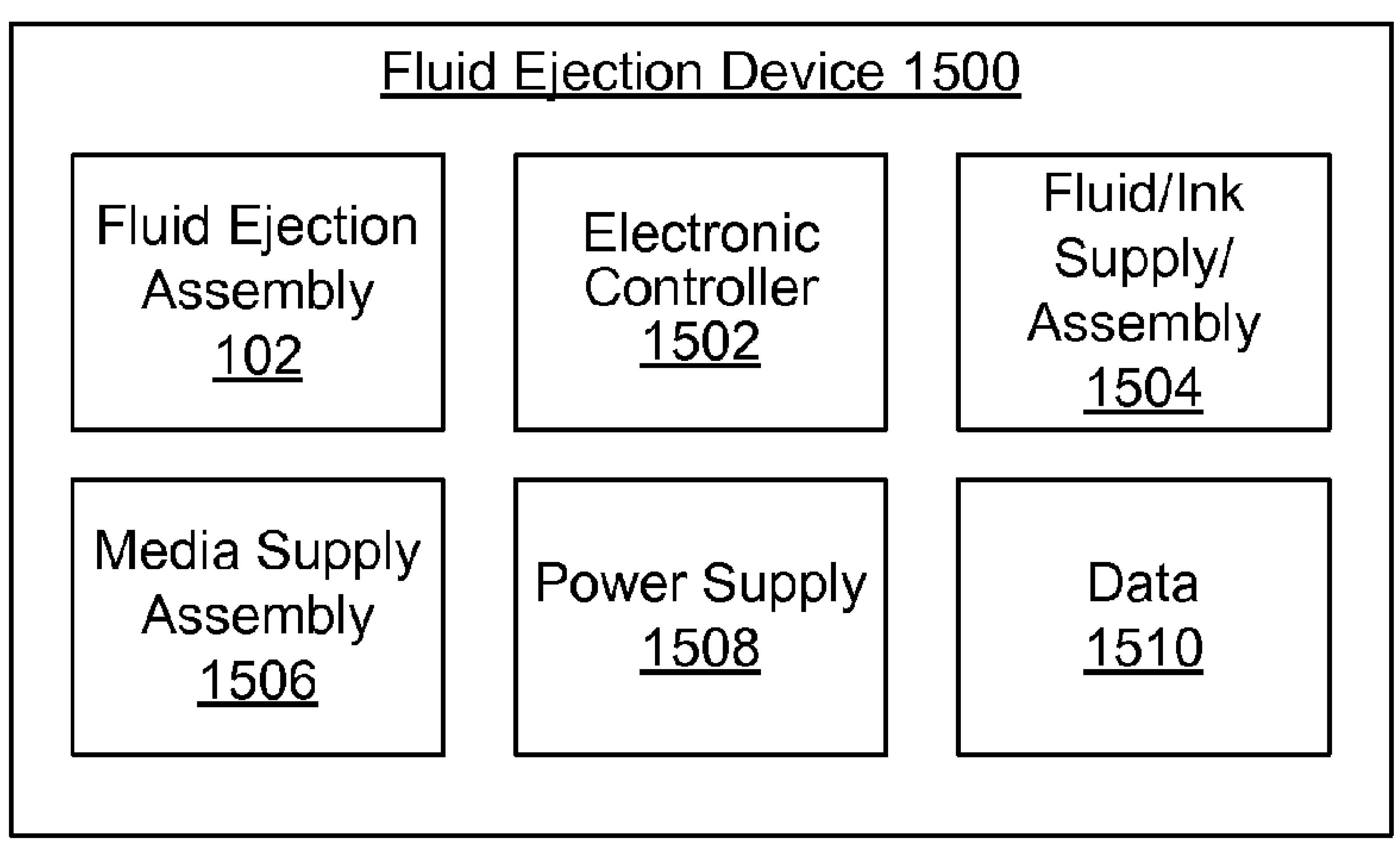
Fluid Ejection Device 1500
Fluid Ejection Assembly 102
Electronic Controller 1502
Fluid/Ink Supply/ Assembly 1504
Media Supply Assembly 1506
Power Supply 1508
Data 1510

FIG. 15

FLUID EJECTION ASSEMBLY WITH CIRCULATION PUMP

BACKGROUND

Fluid ejection devices in inkjet printers provide drop-on-demand ejection of fluid droplets. In general, inkjet printers print images by ejecting ink droplets through a plurality of nozzles onto a print medium, such as a sheet of paper. The nozzles are typically arranged in one or more arrays, such that properly sequenced ejection of ink droplets from the nozzles causes characters or other images to be printed on the print medium as the printhead and the print medium move relative to each other. In a specific example, a thermal inkjet printhead ejects droplets from a nozzle by passing electrical current through a heating element to generate heat and vaporize a small portion of the fluid within a firing chamber. In another example, a piezoelectric inkjet printhead uses a piezoelectric material actuator to generate pressure pulses that force fluid droplets out of a nozzle.

Although inkjet printers provide high print quality at reasonable cost, continued improvement relies on overcoming various challenges that remain in their development. For example, air bubbles are a continuing problem in inkjet printheads. During printing, air from the ink is released and forms bubbles that can migrate from the firing chamber to other locations in the printhead and cause problems such as blocking ink flow, degrading the print quality, causing partly full print cartridges to appear empty, and ink leaks. In addition, pigment-ink vehicle separation (PIVS) remains a problem when using pigment-based inks. Pigment-based inks are preferred in inkjet printing as they tend to be more durable and permanent than dye-based inks. However, during periods of storage or non-use, pigment particles can settle or crash out of the ink vehicle (i.e., PIVS) which can impede or completely block ink flow to the firing chambers and nozzles in the printhead. Other factors such as evaporation of water (for aqueous inks) and solvent (for non-aqueous inks) can also contribute to PIVS and/or increased ink viscosity and viscous plug formation which prevent immediate printing after periods of non-use.

BRIEF DESCRIPTION OF THE DRAWINGS

The present embodiments will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. **1** shows an example of an inkjet pen suitable for incorporating a fluid ejection assembly, according to an embodiment;

FIG. **2**A shows a cross-sectional view and a top down view of a fluid ejection assembly, according to an embodiment;

FIG. **2**B shows a cross-sectional view of a fluid ejection assembly during a drop ejection event, according to an embodiment;

FIG. **3** shows a cross-sectional view and a top down view of a fluid ejection assembly having two fluid feed holes adjacent to either side of an ejection element and one fluid feed hole adjacent to the far side of a pumping element, according to an embodiment;

FIG. **4** shows a cross-sectional view and a top down view of a fluid ejection assembly having two fluid feed holes adjacent to either side of an ejection element and one fluid feed hole adjacent to the near side of a pumping element, according to an embodiment;

FIG. **5** shows a cross-sectional view and a top down view of a fluid ejection assembly having two fluid feed holes, one adjacent to a pump element and one adjacent to an ejection element and both at opposite ends of a fluid channel, according to an embodiment;

FIG. **6** shows a cross-sectional view and a top down view of a fluid ejection assembly having two fluid feed holes, one adjacent to a pump element and one adjacent to an ejection element and both toward the center of a fluid channel, according to an embodiment;

FIG. **7** shows a cross-sectional view and a top down view of a fluid ejection assembly having three fluid feed holes, two adjacent to a pump element and one adjacent to an ejection element at the far side of a fluid channel, according to an embodiment;

FIG. **8** shows a cross-sectional view and a top down view of a fluid ejection assembly having three fluid feed holes, two adjacent to a pump element and one adjacent to an ejection element toward the center of a fluid channel, according to an embodiment;

FIG. **9** shows a top down view of a fluid ejection assembly having pumping elements paired with ejection elements and fluid channels oriented orthogonally with respect to the length of the assembly, according to an embodiment;

FIG. **10** shows a top down view of a fluid ejection assembly having pumping elements paired with ejection elements and fluid channels oriented length-wise with respect to the length of the assembly, according to an embodiment;

FIG. **11** shows a top down view of a fluid ejection assembly having pumping elements paired with ejection elements and u-shaped fluid channels, according to an embodiment;

FIG. **12** shows a top down view of a fluid ejection assembly having pumping elements paired with ejection elements and fluid channels oriented diagonally with respect to the length of the fluid ejection assembly, according to an embodiment;

FIG. **13** shows a top down view of a fluid ejection assembly having paired drop generators with unbalanced circulation channels, according to an embodiment;

FIG. **14** shows a top down view of a fluid ejection assembly having a pumping element shared between a number of surrounding drop generators via circulation channels, according to an embodiment;

FIG. **15** shows a block diagram of a basic fluid ejection device, according to an embodiment of the disclosure.

DETAILED DESCRIPTION

Overview of Problem and Solution

As noted above, various challenges have yet to be overcome in the development of inkjet printing systems. For example, inkjet printheads used in such systems continue to have troubles with ink blockage and/or clogging. Previous solutions to this problem have primarily involved servicing the printheads before and after their use. For example, printheads are typically capped during non-use to prevent nozzles from clogging with dried ink. Prior to their use, nozzles are also primed by spitting ink through them. Drawbacks to these solutions include the inability to print immediately due to the servicing time, and an increase in the total cost of ownership due to the significant amount of ink consumed during servicing. Accordingly, ink blockage and/or clogging in inkjet printing systems remains a fundamental problem that can both degrade overall print quality and increase costs.

There are a number of causes for ink blockage or clogging in a printhead. One cause of ink blockage is an excess of air that accumulates as air bubbles in the printhead. When ink is exposed to air, such as while the ink is stored in an ink reservoir, additional air dissolves into the ink. The subsequent action of firing ink droplets from the firing chamber of the printhead releases excess air from the ink which then accumulates as air bubbles. The bubbles move from the firing chamber to other areas of the printhead where they can block the flow of ink to the printhead and within the printhead.

Pigment-based inks can also cause ink blockage or clogging in printheads. Inkjet printing systems use pigment-based inks and dye-based inks, and while there are advantages and disadvantages with both types of ink, pigment-based inks are generally preferred. In dye-based inks the dye particles are dissolved in liquid so the ink tends to soak deeper into the paper. This makes dye-based ink less efficient and it can reduce the image quality as the ink bleeds at the edges of the image. Pigment-based inks, by contrast, consist of an ink vehicle and high concentrations of insoluble pigment particles coated with a dispersant that enables the particles to remain suspended in the ink vehicle. This helps pigment inks stay more on the surface of the paper rather than soaking into the paper. Pigment ink is therefore more efficient than dye ink because less ink is needed to create the same color intensity in a printed image. Pigment inks also tend to be more durable and permanent than dye inks as they smear less than dye inks when they encounter water.

One drawback with pigment-based inks, however, is that ink blockage can occur in the inkjet printhead after shipping and prolonged storage, resulting in poor out-of-box performance of inkjet pens. Inkjet pens have a printhead affixed at one end that is internally coupled to a supply of ink. The ink supply may be self-contained within the pen body or it may reside on the printer outside of the pen and be coupled to the printhead through the pen body. Over long periods of storage, gravitational effects on the large pigment particles and/or degradation of the dispersant can cause pigment settling or crashing, which is known as PIVS (pigment-ink vehicle separation). The settling or crashing of pigment particles can impede or completely block ink flow to the firing chambers and nozzles in the printhead which can result in poor out-of-box performance by the printhead and reduced image quality.

Other factors such as evaporation of water and solvent from the ink can also contribute to PIVS and/or increased ink viscosity and viscous plug formation which prevent immediate printing after periods of non-use.

Embodiments of the present disclosure help to overcome the problem of ink blockage or clogging in inkjet printheads, generally through the use of a fluid ejection assembly having a fluid circulation pump. The pump is formed on a membrane over a fluid slot in an underlying substrate, and is asymmetrically located along the length of a fluid channel (i.e., toward one end of the channel) in order to create a directional fluid flow (i.e., fluidic diodicity). During idle time when the fluid ejection assembly is not operating, the pump circulates fluid horizontally through the fluid channel and a firing chamber (i.e., in the plane of the pump and firing chamer). The pump also simultaneously circulates fluid vertically through fluid feed holes formed between the channel and the fluid slot. During normal operation of the fluid ejection assembly, a fluid ejection element in the firing chamber ejects fluid droplets through a nozzle. The action of the fluid ejection element also creates a pumping action that circulates fluid horizontally through the channel and vertically between the channel and the fluid slot. The circulation of fluid during both idle time and active operation of the fluid ejection assembly helps to prevent ink blockage or clogging in inkjet printheads.

In one example embodiment, a fluid ejection assembly includes a fluid slot formed in a first substrate. The top surface of the first substrate is adhered to the bottom surface of a membrane, or second substrate. A channel is formed in a chamber layer disposed on top of the second substrate, and fluid feed holes are formed through the second substrate between the fluid slot and the channel. A fluid ejection element is located near a first end of the channel, and a pump element is located near a second end of the channel to circulate fluid horizontally through the channel and vertically through the fluid feed holes.

In another example embodiment, a fluid ejection assembly includes first and second substrates, with a top surface of the first substrate bonded to a bottom surface of the second substrate. A fluid slot is formed in the first substrate, and a chamber layer having a channel formed therein is disposed on a top surface of the second substrate. Fluid feed holes formed through the second substrate provides fluid communication between the fluid slot and the channel. An ejection element and pumping element are disposed in the channel to provide horizontal fluid circulation through the channel between the pumping element and the ejection element and vertical fluid circulation through the fluid feed holes between the channel and fluid slot.

In another example embodiment a method of circulating fluid in a fluid ejection assembly includes pumping fluid horizontally through a fluid channel between a pump element and an ejection element, and pumping fluid vertically between the fluid channel and a fluid slot through fluid feed holes that extend between the fluid channel and the fluid slot.

Illustrative Embodiments

FIG. **1** shows an example of an inkjet pen **100** suitable for incorporating a fluid ejection assembly **102** as disclosed herein, according to an embodiment. In this embodiment, the fluid ejection assembly **102** is disclosed as a fluid drop jetting printhead **102**. The inkjet pen **100** includes a pen cartridge body **104**, printhead (fluid ejection assembly) **102**, and electrical contacts **106**. Individual fluid drop generators **222** (e.g., see FIG. **2**) in the fluid ejection assembly **102** are energized by electrical signals provided at contacts **106** to eject droplets of fluid from selected nozzles **108** and to circulate fluid within the assembly **102**. Individual pumping elements **224** (e.g., see FIG. **2**) in fluid ejection assembly **102** are also energized by electrical signals provided at contacts **106** to circulate fluid within the assembly **102**. The fluid can be any suitable fluid used in a printing process, such as various printable fluids, inks, pre-treatment compositions, fixers, and the like. In some examples, the fluid can be a fluid other than a printing fluid. The pen **100** may contain its own fluid supply within cartridge body **104**, or it may receive fluid from an external supply (not shown) such as a fluid reservoir connected to pen **100** through a tube, for example. Pens **100** containing their own fluid supplies are generally disposable once the fluid supply is depleted.

FIG. **2**A shows both a cross-sectional view and a top down view of a fluid ejection assembly **102** (printhead **102**), according to an embodiment of the disclosure. Fluid ejection assembly **102** includes a first substrate **200** with a fluid slot **202** formed therein. The elongated fluid slot **202** extends into the plane of FIG. **2**A and is in fluid communication with a fluid supply (not shown), such as a fluid reservoir. The fluid slot **202** is a trench formed in the first substrate **200** such that sidewalls **206** of the slot **202** are formed by the substrate **200**. The top wall **208** of the fluid slot **202** is formed by a portion of the bottom surface of an overlying second substrate or membrane **210**. The second substrate **210** is adhered by the remainder of its bottom surface **208** to the top surface **212** of the first substrate **200**. The first and second substrates **200**, **210**, are formed from SOI (silicon on insulator) wafers in standard micro-fabrication processes that are well-known to those skilled in the art (e.g., electroforming, laser ablation, anisotropic etching, sputtering, dry etching, photolithography, casting, molding, stamping, and machining). Silicon dioxide ($SiO2$) layers **214** in the SOI substrates provide a mechanism for achieving accurate etch depths during fabrication while forming features such as the fluid slot **202**.

A chamber layer **216** disposed on top of the second substrate **210** includes a fluid channel **218** formed within the layer **216**. Fluid feed holes **220** (**220**A and **220**B) extend through the second substrate **210** (which forms the top **208** of the fluid slot **202**) and provide fluid communication between the fluid slot **202** and the fluid channel **218**. The fluid channel **218** includes a drop generator **222** disposed toward one end of the channel **218** and a fluid pumping element **224** disposed toward the other end of the channel **218**. The drop generator **210** includes a nozzle **226** formed in a nozzle plate **228** (or top hat layer), a firing chamber **230**, and an ejection or firing element **232** disposed in the firing chamber **230**. The firing chamber **230** is an extension of, and part of, the fluid channel **218**. The firing chamber **230** and the fluid channel **218** widths can be specified independently to optimize fluid ejection and pumping. Ejection element **232** can be any device capable of operating to eject fluid drops through a corresponding nozzle **226**, such as a thermal resistor or piezoelectric actuator. In the illustrated embodiment, ejection element **232** is a thermal resistor formed of a thin film stack applied on top of the second substrate **210**. The thin film stack generally includes an oxide layer, a metal layer defining the ejection element **232**, conductive traces, and a passivation layer (not individually shown).

Fluid pumping element **224** is also disposed on the top surface of the second substrate **210**. Pump element **224** can be any device capable of operating to generate motion in the fluid and create fluid circulation as discussed herein, such as a thermal resistor. Although the pumping element **224** is discussed as a thermal resistor element, in other embodiments it can be any of various types of pumping elements that may be suitably deployed in a channel **218** of a fluid ejection assembly **102**. For example, in different embodiments fluid pumping element **224** might be implemented as a piezoelectric actuator pump, an electrostatic pump, an electro hydrodynamic pump, or a peristaltic pump. In the illustrated embodiment, like ejection element **232**, the pump element **224** is a thermal resistor formed of a thin film stack applied on top of the second substrate **210**. In embodiments where the fluid pump **224** is a thermal resistor, a fluid pumping action is achieved by energizing the pump element **224** (i.e., thermal resistor) with an electrical current. The current causes the resistive pump element **224** to heat rapidly, which in turn superheats and vaporizes a thin layer of fluid in contact with the pump element **224**. The expanding vapor bubble forces fluid away from the pump **224** in both directions within the channel **218**. As discussed below, however, the asymmetric placement of the pump **224** with respect to the length or center of the channel **218** results in a net flow of fluid toward the long side of the channel **218**.

The exact location of the fluid pumping element **224** within the fluid channel **218** may vary somewhat, but in any case will be asymmetrically located with respect to the center point of the length of the fluid channel **218**. For example, assuming the length of a fluid channel **218** in FIG. **2**A extends from the fluid feed hole **220**B shown at the far left side of FIG. **2**A to the fluid feed hole **220**A at the far right side of FIG. **2**A, then the approximate center of the channel **218** is located midway between these far left and far right fluid feed holes. Thus, the fluid pumping element **224** is located asymmetrically with respect to the center of the channel **218** toward the fluid feed hole **220**A at the far right side of the channel **218**. The asymmetric location of the fluid pumping element **224** creates a short side of the channel **218** between the pump **224** and the fluid slot **202**, and a long side of the channel **218** that extends toward the center of the channel **218** and the drop generator **222**.

The asymmetric location of the fluid pumping element **224** within the fluid channel **218** is the basis for a uni-directional flow of fluid (i.e., fluidic diodicity). The grey arrows **234** in FIG. **2**A illustrate the general direction of fluid flow and fluid circulation created by the pumping action of the pumping element **224**. The asymmetric placement of the pump **224** toward a short side of the channel **218** results in a net fluid flow in a direction toward the center or long side of the channel **218** (i.e., toward drop generator **222**). As generally indicated by the grey directional arrows **234**, the pumping element **224** circulates fluid vertically upward from the fluid slot **202** into the channel **218** through fluid feed holes **220**A. The fluid is then pumped horizontally through the channel **218** toward drop generator **222** (i.e., in the plane of the pump **224** and ejection element **232**/firing chamber **230**), and then back into the fluid slot **202** in a vertical direction through fluid feed holes **220**B.

FIG. **2**B shows a cross-sectional view of a fluid ejection assembly **102** during a drop ejection event, according to an embodiment of the disclosure. During normal operation of the fluid ejection assembly, a fluid droplet **236** is ejected from a chamber **230** through a corresponding nozzle **226** by activating a corresponding ejection element **232**. The chamber **230** is then refilled with fluid circulating vertically upward from fluid slot **202** through fluid feed holes **220**B in preparation for ejecting another fluid droplet. More specifically, electric current passed through the thermal resistor ejection element **232** results in rapid heating of the element **232**, and a thin layer of fluid adjacent to the element **232** is superheated. The superheated fluid vaporizes, creating a vapor bubble in the corresponding firing chamber **230**, and the rapidly expanding bubble forces a fluid droplet **236** out of the corresponding nozzle **226**. When the ejection element **232** cools, the vapor bubble quickly collapses, drawing more fluid vertically upward through fluid feed holes **220**B from fluid slot **202** and into the firing chamber **230** in preparation for ejecting another drop from the nozzle **226**.

Thus, during normal drop ejection events it is apparent that the ejection element **232** acts in a dual capacity to eject fluid drops through nozzle **226** as well as circulate fluid within the fluid ejection assembly **102**. The grey arrows **234** in FIG. **2**B illustrate the general direction of fluid flow and fluid circulation created by the pumping action of the ejection element **232** during a drop ejection event. At first, as the rapidly expanding bubble forces a fluid droplet **236** out of the nozzle **226**, fluid in channel **218** circulates horizontally away from the drop generator **222** toward the center or long side of the channel **218**, in a manner similar to, but in the opposite direction of, that described above regarding the pumping element **224**. As the vapor bubble collapses, fluid circulates vertically upward through fluid feed holes **220**B into the chamber **230** and channel **218** to refill the void left by the ejected fluid drop **236**. Thus, during fluid drop ejection, the ejection element **232** also acts as a pumping element to circulate fluid in both vertical and horizontal directions within the fluid ejection assembly **102**, in much the same way as the pumping element **224**. As noted above, the firing chamber **230** and the fluid channel **218** dimensions are independently specified to optimize both fluid ejection and pumping.

FIGS. **3-14** show varying views of a fluid ejection assembly **102** with variations in the structure and/or layout of the fluid channels **218**, the fluid feed holes **220** that extend between the fluid slots **202** and channels **218**, and the pumping elements **224** and ejection elements **232**, according to embodiments of the disclosure. FIG. **3**, for example shows a cross-sectional view and a top down view of a fluid ejection assembly **102** having two fluid feed holes **220**B that are adjacent to either side of the ejection element **232** as in the FIG. **2** embodiment, but only one fluid feed hole **220**A adjacent to the far side of the pumping element **224**, according to an embodiment of the disclosure. As shown by the grey directional arrow **234**, the pumping action of pump element **224** in the FIG. **3** embodiment circulates fluid vertically upward from the fluid slot **202** into the channel **218** through the single fluid feed hole **220**A, and horizontally through the channel **218** toward the center or long side of the channel **218** (i.e., toward drop generator **222**). Although not illustrated, during normal drop ejection events the ejection element **232** acts in a dual capacity to eject fluid drops through nozzle **226** as well as circulate fluid within the fluid ejection assembly **102**. As in the FIG. **2** embodiment, the ejection element **232** circulates fluid in channel **218** horizontally away from the drop generator **222** toward the center or long side of the channel **218**, and then vertically upward through fluid feed holes **220**B into the chamber **230** and channel **218** to refill the void left by an ejected fluid drop **236** as the ejection element **232** cools and the vaporization bubble shrinks.

FIG. **4** shows a cross-sectional view and a top down view of a fluid ejection assembly **102** having two fluid feed holes **220**B that are adjacent to either side of the ejection element **232** as in the FIG. **2** embodiment, but only one fluid feed hole **220**A adjacent to the near side of pumping element **224**, according to an embodiment of the disclosure. As shown by the grey directional arrow **234**, the pumping action of pump element **224** in the FIG. **4** embodiment circulates fluid vertically upward from the fluid slot **202** into the channel **218** through the single fluid feed hole **220**A, and horizontally through the channel **218** toward the center or long side of the channel **218** (i.e., toward drop generator **222**). Again, during normal drop ejection events the ejection element **232** ejects fluid drops through nozzle **226** as well as circulates fluid within the fluid ejection assembly **102**. The ejection element **232** circulates fluid in channel **218** horizontally away from the drop generator **222** toward the center or long side of the channel **218**, and then vertically upward through fluid feed holes **220**B into the chamber **230** and channel **218** to refill the void left by an ejected fluid drop **236**.

FIGS. **5-8** show additional example configurations of fluid channels **218**, fluid feed holes, pumping elements **224** and ejection elements **232**, within a fluid ejection assembly **102**, and the general direction of fluid circulation generated by the respective pumping elements **224**, according to embodiments of the disclosure. In the FIG. **5** embodiment, a fluid ejection assembly **102** has two fluid feed holes **220**A and **220**B, one adjacent to pumping element **224** and at the far right side of channel **218** and the other adjacent to ejection element **232** and at the far left side of channel **218**. In the FIG. **6** embodiment, a fluid ejection assembly **102** also has two fluid feed holes **220**A and **220**B. One fluid feed hole **220**A is adjacent to pumping element **224** and the other fluid feed hole **220**B is adjacent to ejection element **232**, and both are between the pumping element **224** and ejection element **232** toward the center of the channel **218**. In the FIG. **7** and FIG. **8** embodiments, fluid ejection assemblies **102** have three fluid feed holes **220** with two fluid feed holes **220**A adjacent to either side of the pumping element **224**. In FIG. **7**, the third fluid feed hole **220**B is adjacent to the ejection element **232** at the far left side of channel **218**, and in FIG. **8**, the third fluid feed hole **220**B is adjacent to the ejection element **232** toward the center of channel **218**.

FIGS. **9** and **10** show top down views of fluid ejection assemblies **102** where pumping elements **224** are paired with ejection elements **232** within a fluid channel **218**, according to embodiments of the disclosure. In the FIG. **9** embodiment, the lengths of the fluid channels **218** are oriented orthogonal to the length of the fluid ejection assembly **102** and underlying fluid slot **202** (not shown). In the FIG. **10** embodiment, the lengths of the fluid channels **218** are oriented such that they correspond with the length of the fluid ejection assembly **102** and underlying fluid slot **202** (not shown). In both cases, the asymmetric location of the pumping element **224** and ejection element **232** in each fluid channel **218** results in fluid circulation back and forth between the pumping element **224** and ejection element **232** and to and from the underlying fluid slot **202** through fluid feed holes **220**. For example, in the FIG. **9** embodiment, pumping element **224** circulates fluid vertically upward (i.e., out of the plane) from the underlying fluid slot **202** through fluid feed holes **220**A, then horizontally through the fluid channel **218** from the pumping element **224** to the ejection element **232** (i.e., within the plane of the pump element **224**, ejection element **232**, etc.), and vertically downward (i.e., into the plane) back into the fluid slot **202** through fluid feed holes **220**B. When the ejection element **232** activates to eject fluid drops, the pumping effect of the ejection element **232** causes fluid to circulate mostly in a reverse direction. Fluid circulates in a similar manner in the FIG. **10** embodiment.

FIGS. **11** and **12** show top down views of fluid ejection assemblies **102** where pumping elements **224** are paired with ejection elements **232** within a fluid channels **218** having different shapes, according to embodiments of the disclosure. In the FIG. **11** embodiment, the fluid channels **218** are u-shaped with the pump element **224** and fluid feed holes **220**A on one side of the "u", and the ejection element **232** and fluid feed holes **220**B on the other side of the "u". The pumping element **224** circulates fluid vertically upward (i.e., out of the plane) from the underlying fluid slot **202** through fluid feed holes **220**A, then horizontally through the u-shaped fluid channel **218** from the pumping element **224** to the ejection element **232** (i.e., within the plane of the pump element **224**, ejection element **232**, etc.), and vertically downward (i.e., into the plane) back into the fluid slot **202** through fluid feed holes **220**B. When the ejection element **232** activates to eject fluid drops, the pumping effect of the ejection element **232** causes fluid to circulate mostly in a reverse direction. The FIG. **12** embodiment has fluid channels **218** that are oriented diagonally with respect to the length of the fluid ejection assembly **102** and underlying fluid ejection slot **202**. Fluid circulation in the FIG. **12** embodiment is similar to the FIG. **11** embodiment.

FIG. **13** shows a top down view of a fluid ejection assembly **102** having paired drop generators **222** with unbalanced circulation channels **218**, according to an embodiment of the disclosure. As in previous embodiments, the asymmetric location of the fluid pumping element **224** within the fluid channel **218** is the basis for a uni-directional flow of fluid (i.e., fluidic diodicity). The asymmetric placement of the pump element **224** toward one end of the channel **218** results in a net flow of fluid toward the long side of the channel **218**. Thus, in the FIG. **13** embodiment, pump element **224** operates to circulate fluid horizontally from right to left within channel **218** (i.e., within the plane of the pump **224**, ejection element **232**,etc.), and vertically upward (i.e., out of the plane) through the fluid feed holes **220** on the right side of the channel **218** and vertically downward (i.e., into the plane) through the fluid feed holes **220** on the left side of the channel **218**.

FIG. **14** shows a top down view of a fluid ejection assembly **102** having a pumping element shared between a number of surrounding drop generators **222** via circulation channels **218**, according to an embodiment of the disclosure. The central location of the pumping element **224** between the four drop generators **222** results in fluid circulating vertically upward (i.e., out of the plane) through the fluid feed holes **220** adjacent to the pump **224**, horizontally through the cannels **218** to each of the drop generators **222** (i.e., within the plane of the pump **224**, ejection elements **232**,etc.), and vertically downward (i.e., into the plane) through the fluid feed holes **220** on either side of the ejection elements **232**.

FIG. **15** shows a block diagram of a basic fluid ejection device, according to an embodiment of the disclosure. The fluid ejection device **1500** includes an electronic controller **1502** and a fluid ejection assembly **102**. Fluid ejection assembly **102** can be any embodiment of a fluid ejection assembly **102** described, illustrated and/or contemplated by the present disclosure. Electronic controller **1502** typically includes a processor, firmware, and other electronics for communicating with and controlling fluid ejection assembly **102** to eject fluid droplets in a precise manner.

In one embodiment, fluid ejection device **1500** may be an inkjet printing device. As such, fluid ejection device **1500** may also include a fluid/ink supply and assembly **1504** to supply fluid to fluid ejection assembly **102**, a media transport assembly **1506** to provide media for receiving patterns of ejected fluid droplets, and a power supply **1508**. In general, electronic controller **1502** receives data **1510** from a host system, such as a computer. The data **1510** represents, for example, a document and/or file to be printed and forms a print job that includes one or more print job commands and/or command parameters. From the data **1510**, electronic controller **1002** defines a pattern of drops to eject which form characters, symbols, and/or other graphics or images.

What is claimed is:

1. A fluid ejection assembly comprising:

a fluid slot formed in a first substrate;

a chamber layer disposed on top of a second substrate, wherein a bottom surface of the second substrate is adhered to a top surface of the first substrate;

a nozzle plate formed over the chamber layer;

a channel formed in the chamber layer between the nozzle plate and second substrate;

a fluid feed holes formed between the fluid slot and the channel;

a fluid ejection element at a first end of the channel; and

a pump element formed on the second substrate within the channel at a second end of the channel to circulate fluid horizontally through the channel and vertically through the fluid feed holes.

2. A fluid ejection assembly as in claim **1**, wherein the fluid feed holes comprise:

a first fluid feed hole adjacent to the fluid ejection element; and

a second fluid feed hole adjacent to the pump element.

3. A fluid ejection assembly as in claim **2**, wherein the first fluid feed hole is between the fluid ejection element and the first end of the channel.

4. A fluid ejection assembly as in claim **2**, wherein the second fluid feed hole is between the pump element and the second end of the channel.

5. A fluid ejection assembly as in claim **1**, wherein the fluid feed holes comprise:

first and second fluid feed holes adjacent to and on either side of the fluid ejection element; and

a third fluid feed hole adjacent to the pump element.

6. A fluid ejection assembly as in claim **1**, wherein the fluid feed holes comprise:

first and second fluid feed holes adjacent to and on either side of the pump element; and

a third fluid feed hole adjacent to the fluid ejection element.

7. A fluid ejection assembly as in claim **1**, wherein the fluid feed holes comprise:

first and second fluid feed holes adjacent to and on either side of the fluid ejection element; and

third and fourth fluid feed holes adjacent to and on either side of the pump element.

8. A fluid ejection assembly as in claim **1**, wherein the channel is u-shaped.

9. A fluid ejection assembly as in claim **1**, wherein the channel is diagonally oriented with respect to a long dimension of the fluid slot.

10. A fluid ejection assembly comprising:

first and second substrates, a top surface of the first substrate bonded to a bottom surface of the second substrate;

a fluid slot formed in the first substrate;

a chamber layer formed on a top surface of the second substrate and having a channel defined therein;

a nozzle plate formed over the chamber layer;

fluid feed holes formed through the second substrate to provide fluid communication between the fluid slot and the channel;

an ejection element disposed in the channel; and

a pumping element formed on the second substrate within the channel to provide horizontal fluid circulation through the channel between the pumping element and the ejection element and vertical fluid circulation through the fluid feed holes between the channel and fluid slot.

11. A fluid ejection assembly as in claim **10**, wherein the channel comprises multiple channels that intersect at a first end, and wherein the pumping element is disposed at the intersection of the channels and an ejection element is disposed at a second end of each channel, the pumping element to provide horizontal fluid circulation through the channels between the pumping element and each ejection element and vertical fluid circulation through the fluid feed holes between the channels and fluid slot.

12. A fluid ejection assembly as in claim **10**, wherein the pumping element is located asymmetrically with respect to a central point along the channel.

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